# CFDTD Solution For Large Waveguide Slot Arrays

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## I. Introduction

The Finite Difference Time Domain (FDTD) technique consists of simulating time varying electromagnetic fields in various media with Maxwell's curl equations in the form of finite difference equations, which are then used in a leapfrog fashion to incrementally advance the discretized electromagnetic fields forward in time and solve for them at alternating intervals in space [1]. The main drawback to the use of the FDTD method is the need for large computational resources, notably memory. The amount of memory required is a function of the grid employed to divide the problem space into individual cells. The memory requirements increase with the volume in the computational domain. The Conformal FDTD (CFDTD) code is being developed jointly by RMA [2] and the Navy for direct simulation of large complicated structures such as slotted waveguide array antennas. The ability to run on a parallel computing system and its highly versatile non-uniform meshing tool are two aspects of CFDTD that ease otherwise restrictive computational resource demands. CFDTD code performance including partitioning for parallel processing and computing runtimes are presented herein.

## II. Array Design

Slotted waveguide arrays have many applications in military microwave communications and radar systems [3]. Practical implementations often require large arrays consisting of many radiators in order to achieve the necessary directivity with specified sidelobe levels. Two test cases were examined for this discussion. The first test case consists of an array of 48 waveguide longitudinal shunt slots, while the second test case has 96 similar elements. The radiating elements are arranged in a rectangular formation using identical waveguides. In the top wall of each waveguide 6 shunt slots are positioned offset from the centerline to allow proper phasing for broadside radiation. The slots, which are spaced $\lambda_g/2$ apart, have identical widths, but have lengths adjusted to create a taper illumination. Each waveguide is excited with an incident $TE_{10}$ mode at one end and terminated at the opposite end. The waveguide structure has a cross section of 0.837" x 0.2" with finite thicknessess of 0.032" and 0.04" for top and side walls, respectively. A detailed description of the 48 element array is presented in Figure 1.

## III. Modeling

The analysis was conducted using a 16-node Linux cluster consisting of 2.4 GHz Pentium 4 processors with a total of 32 GB of RDRAM. Fig. 2 displays a screen capture of the Graphical User Interface, along with the partitioning of the problem space for parallel processing. The computing domain can be divided equally or non-equally among the available processors. For a given antenna problem, the code will allow partitioning along any one of the three principal axes. It is necessary that each node be given at least a certain minimal percentage of the problem to insure solution stability and accuracy. The first case presented in this paper was simulated with equal partitioning between processors (in order to optimize the runtimes) along both the x and y axes. In general, the meshing plays a very important role in achieving accuracy. Both uniform and non-uniform grid options were available; the latter was selected to capture the rapid changes

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| Report Documentation Page | | | | | *Form Approved* *OMB No. 0704-0188* |
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| 1. REPORT DATE **01 JAN 2005** | | 2. REPORT TYPE **N/A** | | | 3. DATES COVERED **-** |
| 4. TITLE AND SUBTITLE **CFDTD Solution For Large Waveguide Slot Arrays** | | | | | 5a. CONTRACT NUMBER |
| | | | | | 5b. GRANT NUMBER |
| | | | | | 5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | | | | | 5d. PROJECT NUMBER |
| | | | | | 5e. TASK NUMBER |
| | | | | | 5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **SSCSD 2825, San Diego, CA 92152** | | | | | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | | | | | 10. SPONSOR/MONITOR'S ACRONYM(S) |
| | | | | | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited** | | | | | |
| 13. SUPPLEMENTARY NOTES **See also ADM001846, Applied Computational Electromagnetics Society 2005 Journal, Newsletter, and Conference., The original document contains color images.** | | | | | |
| 14. ABSTRACT | | | | | |
| 15. SUBJECT TERMS | | | | | |
| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
| a. REPORT **unclassified** | b. ABSTRACT **unclassified** | c. THIS PAGE **unclassified** | **UU** | **4** | |

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

in field distribution in and around the slots, while allowing for the use of larger cells in less critical areas thereby reducing both memory required and runtime. The mesh scheme utilized approximately 2.25 GB of memory. The model was excited with a Gaussian pulse and the simulation was run for 20k time steps. Fig. 3 displays the voltage between the slotted and bottom wall within one of the waveguides. The decay in voltage amplitude as a function of time indicates that solution convergence was achieved. The array was then expanded in the E-plane to include 96 slots. The mesh design remained the same, simply extended along one direction to account for the increased volume of the problem space. The memory utilized increased to 8 GB. The array model could easily be expanded to include more slots to form a much larger array given the memory available. However, this may require increasing the problem space in more than one dimension to avoid the reflection of oblique waves back in to the problem space.

## IV. <u>Results and Discussion</u>

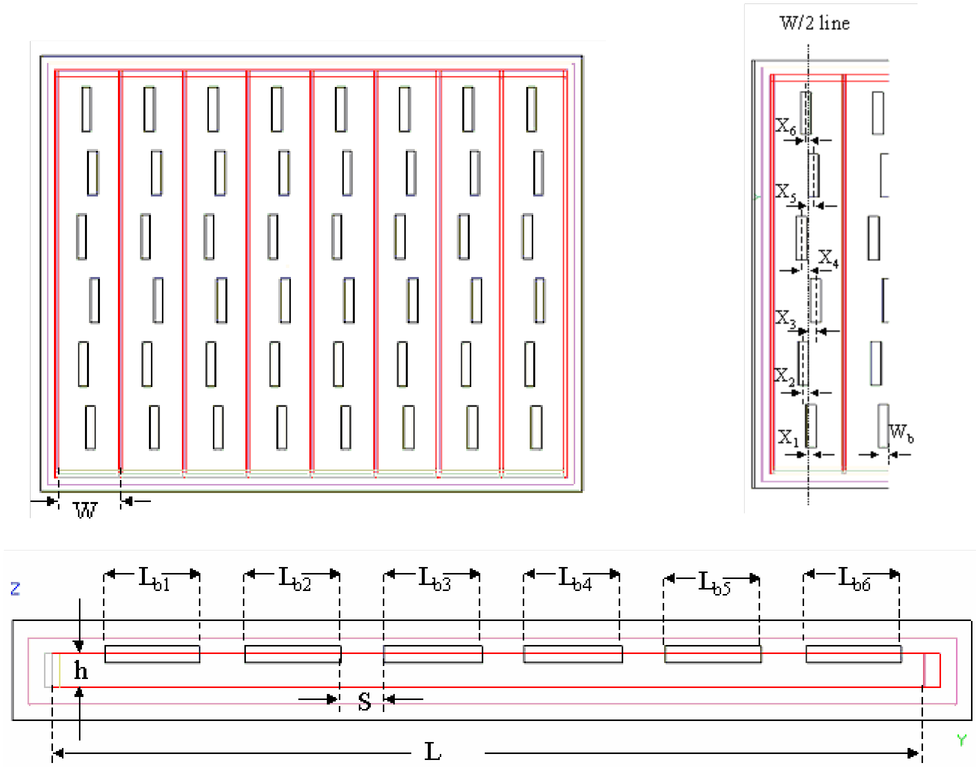
The 48 element slot array analysis was carried out in both x and y partitioning directions. In the x direction, the E- and H-plane radiation patterns computed at a frequency of 9.75 GHz are displayed in Fig. 4. The chart covers $-90^o$ to $+ 90^o$, where $0^o$ represents the boresight direction. The data show that there is a main lobe in the forward direction, with a 3 dB beamwidth of approximately $9^o$ along the E-plane and $15^o$ across the H-plane, respectively. The corresponding pattern directivity is 24.5 dB at the center frequency of 9.75 GHz. The ellipticity in the beam pattern is mainly due to the layout of the antenna since there are only 6 array elements along the $\phi=90^o$ direction, whereas there are 8 elements along $\phi=0^o$. The difference in sidelobe formation between the two planes is due to both layout and the contrasts between the E-plane and H-plane patterns of the individual slot. The first sidelobe is 13 dB below the boresight peak, while the remaining sidelobes are at least 19.6 dB below peak. The CFDTD results are then compared to both measurement and a Method of Moments (MoM) calculation [4], as indicated in Fig. 4. Note that the MoM data assumes slots on an infinite ground plane with uniform fields transverse to all slots. In the CFDTD simulation, the entire antenna problem was treated as a finite 3-D structure with a 5.600 x 7.056 $in^2$ ground plane. Nevertheless, the comparison shows good agreement between different data sets. Fig. 5 shows CFDTD results for partitioning along both the x and y axes. The radiation patterns show the expected identical results. The computational time was slightly faster along the x-axis (3 hr 15min vs. 3 hr 27 min). The radiation pattern for the enlarged array is shown in figure 6. The directivity values for this array range from 27.2 to 27.4 dB over the 9.5 to 10 GHz frequency range. The sidelobes over the angle range of interest are narrower, have a sharper taper, and are more numerous than those of the 48-slot array, all of which is to be expected.

## <u>Acknowledgements</u>

This work was part of the Integrated Topside Design Validated Integrated Physics-based Electromagnetic Radiation (VIPER) Tool Set Development funded by NAVSEA PMS-500.

## <u>References</u>

[1] K. S. Yee, “Numerical solution of initial boundary value problems involving Maxwell’s equations in isotropic media”, IEEE Trans. Antennas and Propagation, Vol. 14, 1966, pp. 302-307.
[2] Raj Mittra & Associates, State College, Pennsylvania.
[3] R. C. Johnson and H. Jasik, Antenna Engineering Handbook, 2 nd Edition, New York: McGraw-Hill, 1984.
[4] H. Y. Yee, “The design of large waveguide arrays of shunt slots”, IEEE Trans. Antennas and Propagation, Vol. 40, 1992, pp. 775.

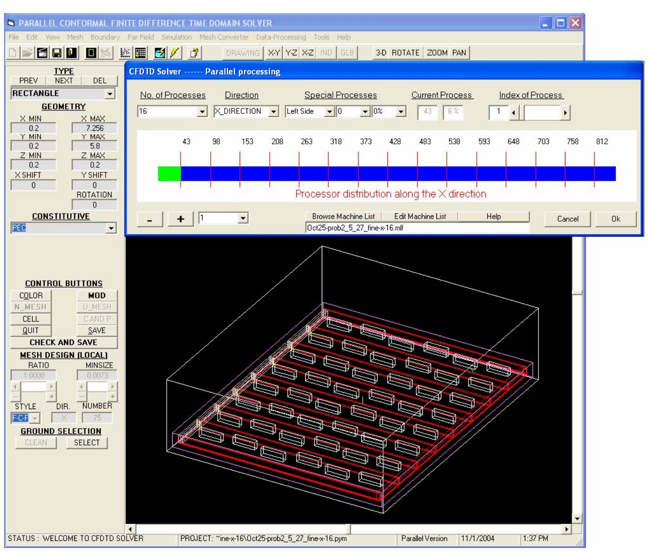



W = 0.837”
$X_1$ = 0.032”
$X_4$ = -0.086”
$L_{b1}$ = $L_{b6}$ = 0.5963”
S = 0.275”

h = 0.2”
$X_2$ = -0.061”
$X_5$ = 0.061”
$L_{b2}$ = $L_{b5}$ = 0.6048”

$W_b$ = 0.125”
$X_3$ = 0.086”
$X_6$ = -0.032”
$L_{b3}$ = $L_{b4}$ = 0.6158”

Figure 1. Slotted Waveguide Antenna Array (48 slots).



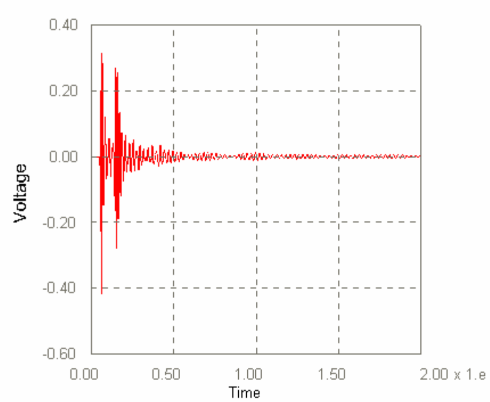
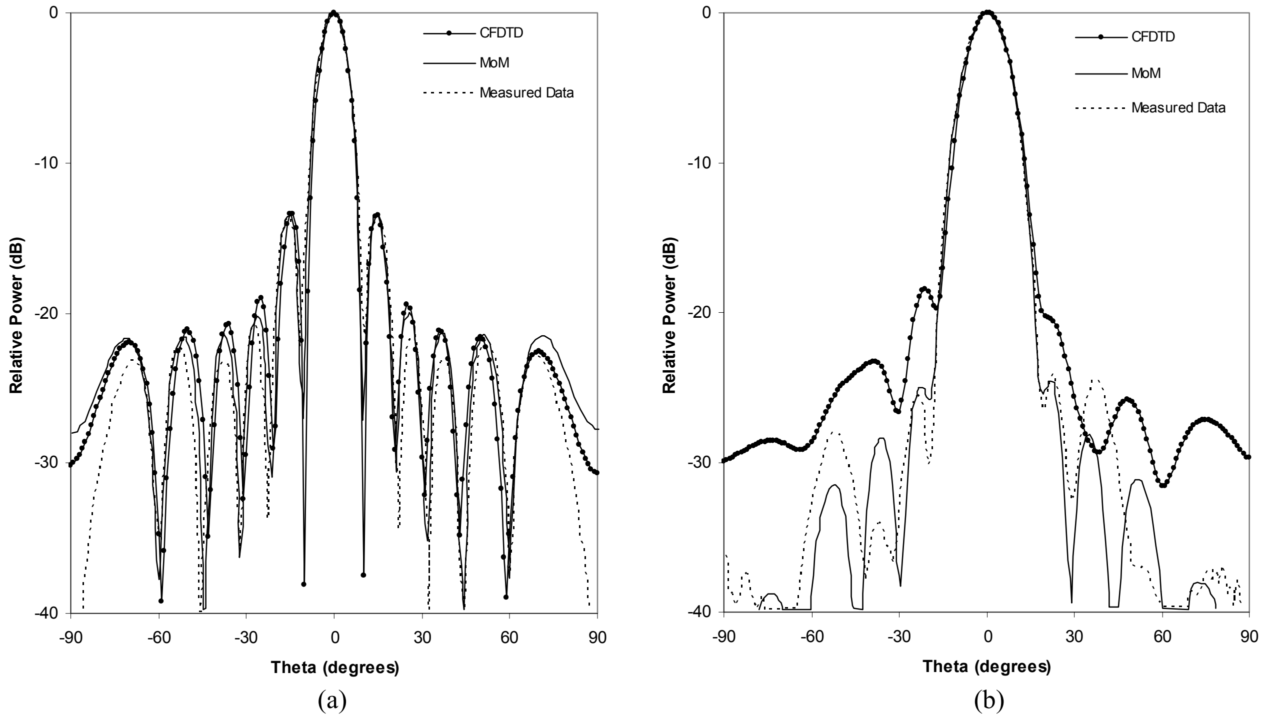




Figure 2. GUI and Partitioning.

Figure 3. Voltage vs. Time.




(a) (b)

Figure 4. E-Plane (a) and H-Plane (b) Radiation Patterns.

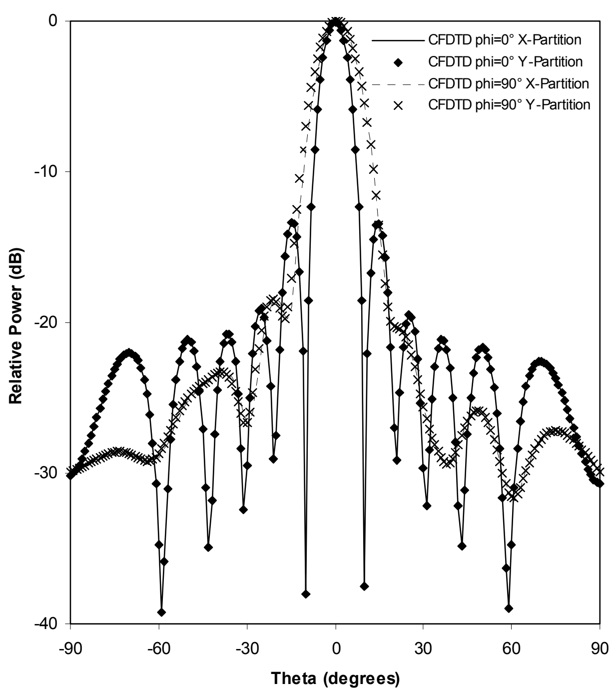



Figure 5. Comparison Between x & y Partitionings.

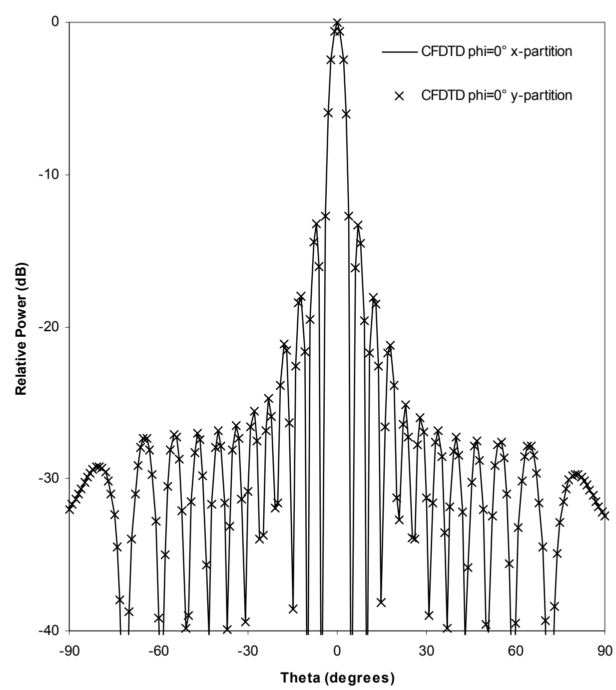



Figure 6. E-Plane Radiation Pattern for 96-Element Slotted Array.